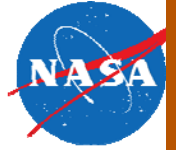


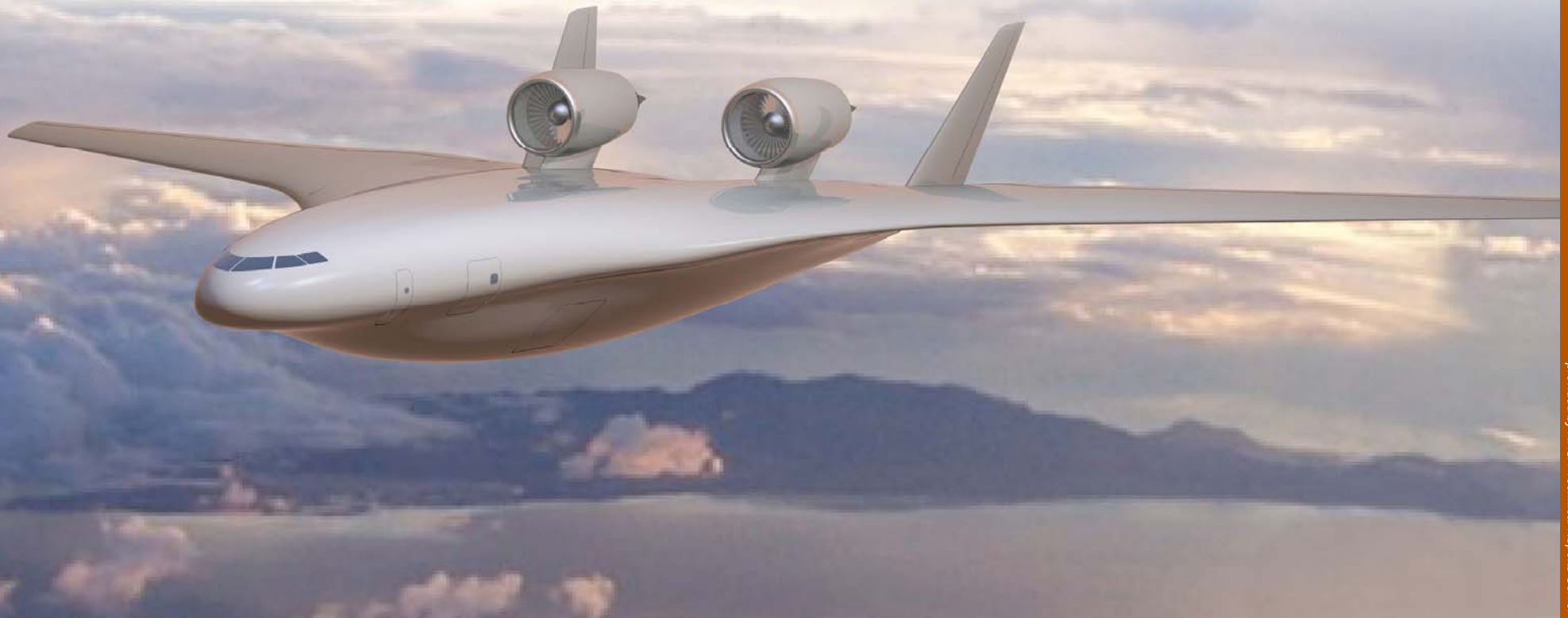
National Aeronautics and Space Administration



Environmentally Responsible Aviation (ERA) Project

Assessing Progress Toward Simultaneous Reductions in Noise, Fuel Burn and NOx

Craig Nickol
VSI Systems Analysis Element Lead
Environmentally Responsible Aviation
(ERA) Project, NASA

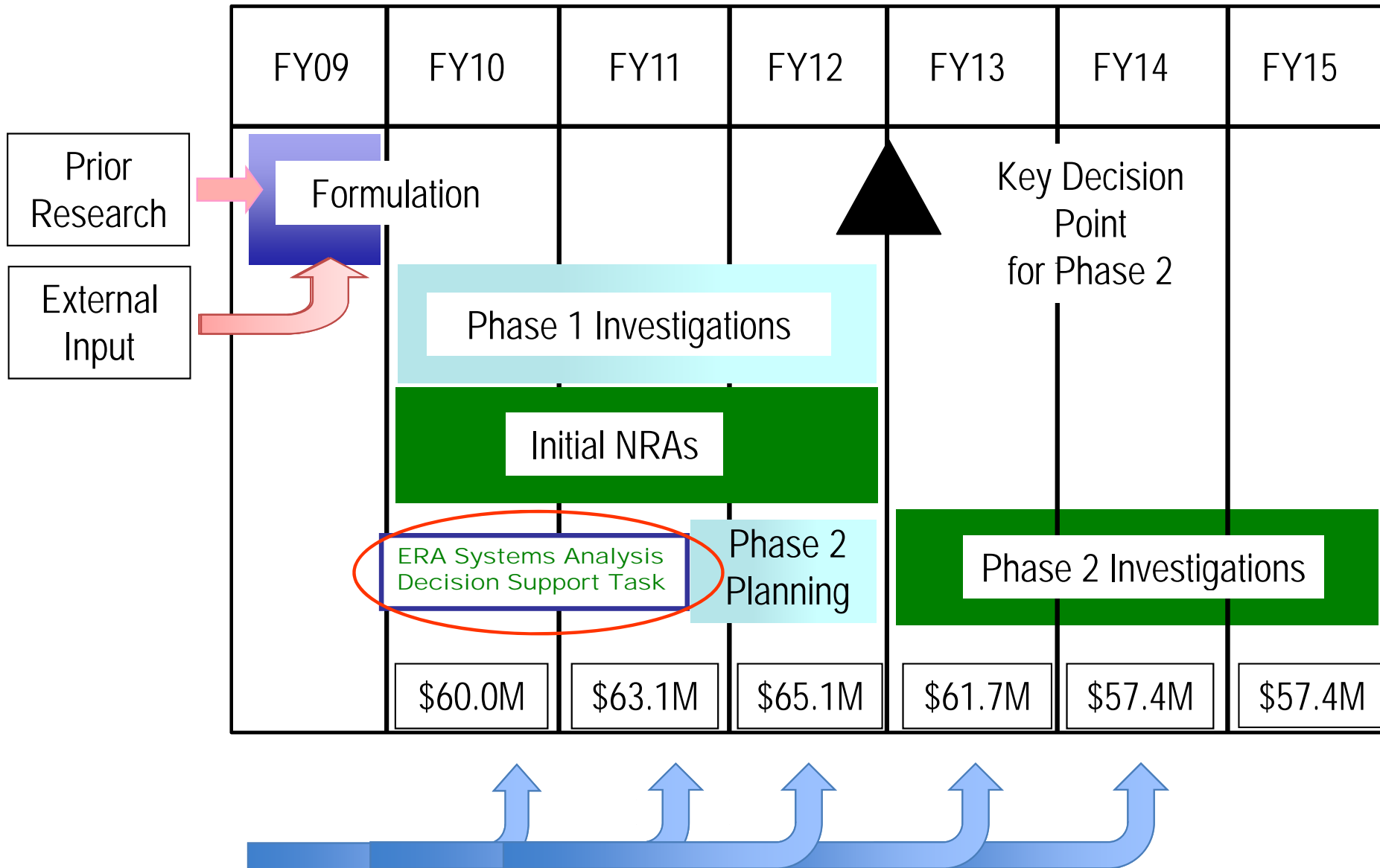




Topics Addressed

- ERA Project Metrics Evolution
- ERA Portfolio Analysis Status
Measuring Progress Towards our Goal
(Top down and Bottoms Up)

ERA Project Overview, Flow And Key Decision Point for Phase 2



Technical input from Fundamental Programs, NRAs, Industry, Academia, Other Gov't Agencies

Refer to Title Slide for Distribution Restrictions

ERA Goals, Objectives & System Level Metrics



ERA Goal

	N+1 = 2015** Technology Benefits Relative To a Single Aisle Reference Configuration	N+2 = 2020** Technology Benefits Relative To a Large Twin Aisle Reference Configuration	N+3 = 2025** Technology Benefits
Noise (cum below Stage 4)	-32 dB	-42 dB	-71 dB
LTO NO _x Emissions (below CAEP 6)	-60%	-75%	better than -75%
Performance: Aircraft Fuel Burn	-33%	-50%	better than -70%
Performance: Field Length	-33%	-50%	exploit metro-plex* concepts

**Technology Readiness Level for key technologies = 4-6. ERA will undertake a time phased approach, TRL 6 by 2015 for “long-pole” technologies

* Concepts that enable optimal use of runways at multiple airports within the metropolitan area

In 2005, market opportunities drove the development of the system level metrics



The market was predicting there would be a single aisle (B737/A320) replacement aircraft by 2015*

- This drove the N+1 focus and metrics to be referenced to SOA single aisle

Also, we projected about 10 years later there would be a large twin aisle (B777) replacement

- This drove the the N+2 focus, and metrics to be referenced to the SOA large twin aisle

*Chinese C919, 168-190 seat class and Russian MC-21, 150-212 seat class
First Flights in 2014?

Market Opportunities - **Current** Forecast



- Beyond 2015, before 2020 – New engines (GTF, LEAP-X)
 - A320 New Engine Option
 - Re-engine B737?
- Beyond 2020, before 2025 – CONVENTIONAL THINKING
 - Single Aisle Replacement (B737/A320)
 - High probability tube and wing, adv engine (open rotor)/combustors, advanced structures, plus laminar flow
 - Large Twin Aisle Replacement (B777, etc)
 - High probability tube and wing, advanced engine/combustors, advanced structures, laminar flow, but HWB likely to be evaluated as serious contender
- 2025 and BEYOND – UNCONVENTIONAL THINKING – WHAT IF REPLACEMENTS SLIP TO RIGHT?
 - NASA N+2 and N+3 studies identifying key, time-phased technology roadmaps, and “system ready” unconventional configurations
 - Joined wing, trussed braced wing, double bubble, HWB, etc.
 - Hybrid/JP8/battery, cryo-cooling, low energy nuclear reactors, etc....

Assess impacts of technology investments on market opportunities



2010 Assessment	Re-engine/Retrofits	Replacement Conventional	Replacement Unconventional
2010 Assessment	Re-engine/Retrofits	Replacement Conventional	Replacement Unconventional
2010 Assessment	Re-engine/Retrofits	Replacement Conventional	Replacement Unconventional
2010 Assessment	Re-engine/Retrofits	Replacement Conventional	Replacement Unconventional
2010 Assessment Very Large	Re-engine/Retrofits	Replacement Conventional	Replacement Unconventional
Noise (cum below Stage 4)			
LTO NO _x Emissions (below CAEP 6)			
Performance: Aircraft Fuel Burn			
TIME NOW			→ 2025 +

ERA Systems Analysis Overview



ERA systems analysis tasks for measuring progress towards our goal

- “Top Down” Methodology Overview
- Concept Modeling Results Summary
- Large Twin Aisle Class Advanced Tube + Wing and HWB

Georgia Tech’s Aerospace Systems Design Lab (ASDL) is supporting ERA to perform this analysis

ERA N+2 Technology Database

(3rd Iteration Completed August 2010)

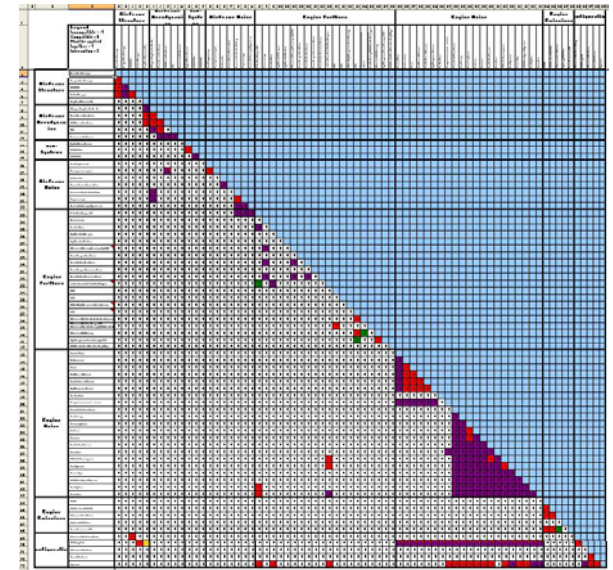


ERA Technology Database Development Approach:

- Multiple Data Sources:
 - ERA Phase 1 Project Plans
 - GA Tech JPDO/FAA EDS Database
 - NASA N+3 NRA Reports
 - FAP/SFW Planning Reports
 - ERA Project Engineers
 - ERA Discipline Experts
- Technologies with TRL too low or too high for ERA were removed

Technology Database Analysis Report includes:

- Technology Description
- Current and Projected TRLs
- Technology Compatibility Matrix (interactions for 65 Technologies)
- Summary Spreadsheet (19 airframe technologies; 46 engine technologies)
- Projected benefits and impacts
- Modeling approach in EDS

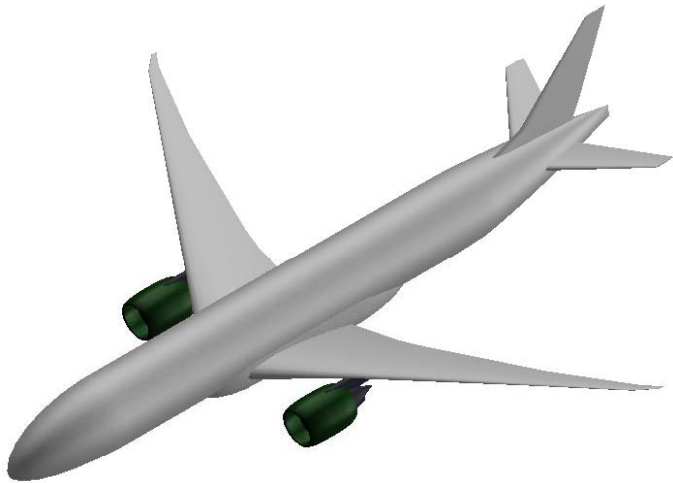


Technology Compatibility Matrix
Shows Interactions for 65 Technologies

Initial Technology “Collectors”

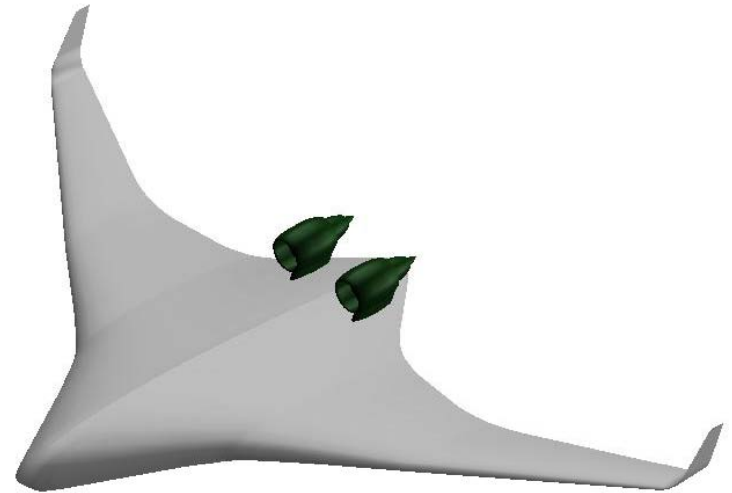


Advanced Tube and Wing



*Engine Options:
Advanced direct drive
Geared Turbofan
Open Rotor*

Hybrid Wing Body



- Potential ERA airframe and engine technology packages installed on both conventional and advanced configurations
- Fuel burn, noise and emissions are estimated using models developed in NASA's standard toolset (NPSS/WATE, FLOPS, ANOPP) which has been integrated into Ga Tech's Environmental Design Space (EDS) tool
- EDS can feed global tools in AEDT for fleet level global impact estimates
- Seeking additional technology collector advanced configurations through NRA and in-house efforts

Technology Rankings



- Both deterministic and probabilistic assessments will be performed to determine the ERA technology package that results in the best overall performance (probabilistic assessment will provide a quantified confidence level)

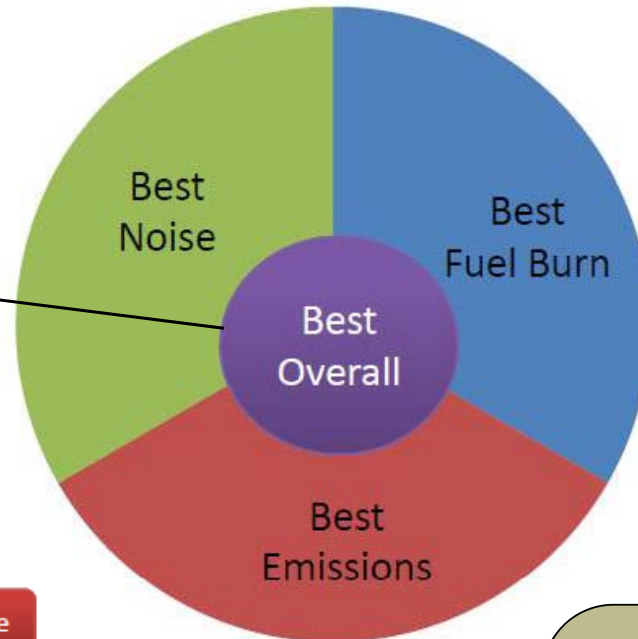
Product

Recommendations for
ERA Phase II Portfolio:

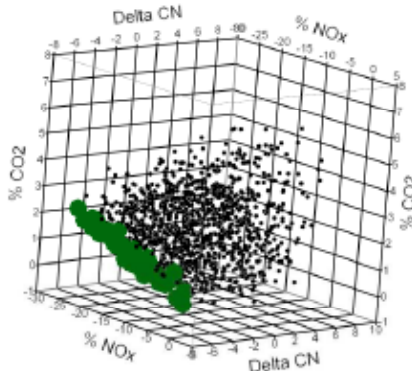
Technology Package for
Best Overall Performance:

Airframe Tech 1
Airframe Tech 2
Airframe Tech 3
Engine Tech 1
Engine Tech 2
Engine Tech 3

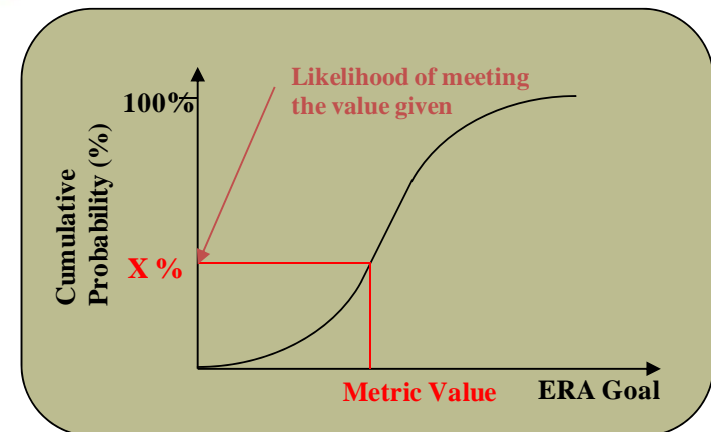
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Combinatorial Space



Deterministic – Cloud of Point Solutions



Probabilistic – Confidence in meeting a metric

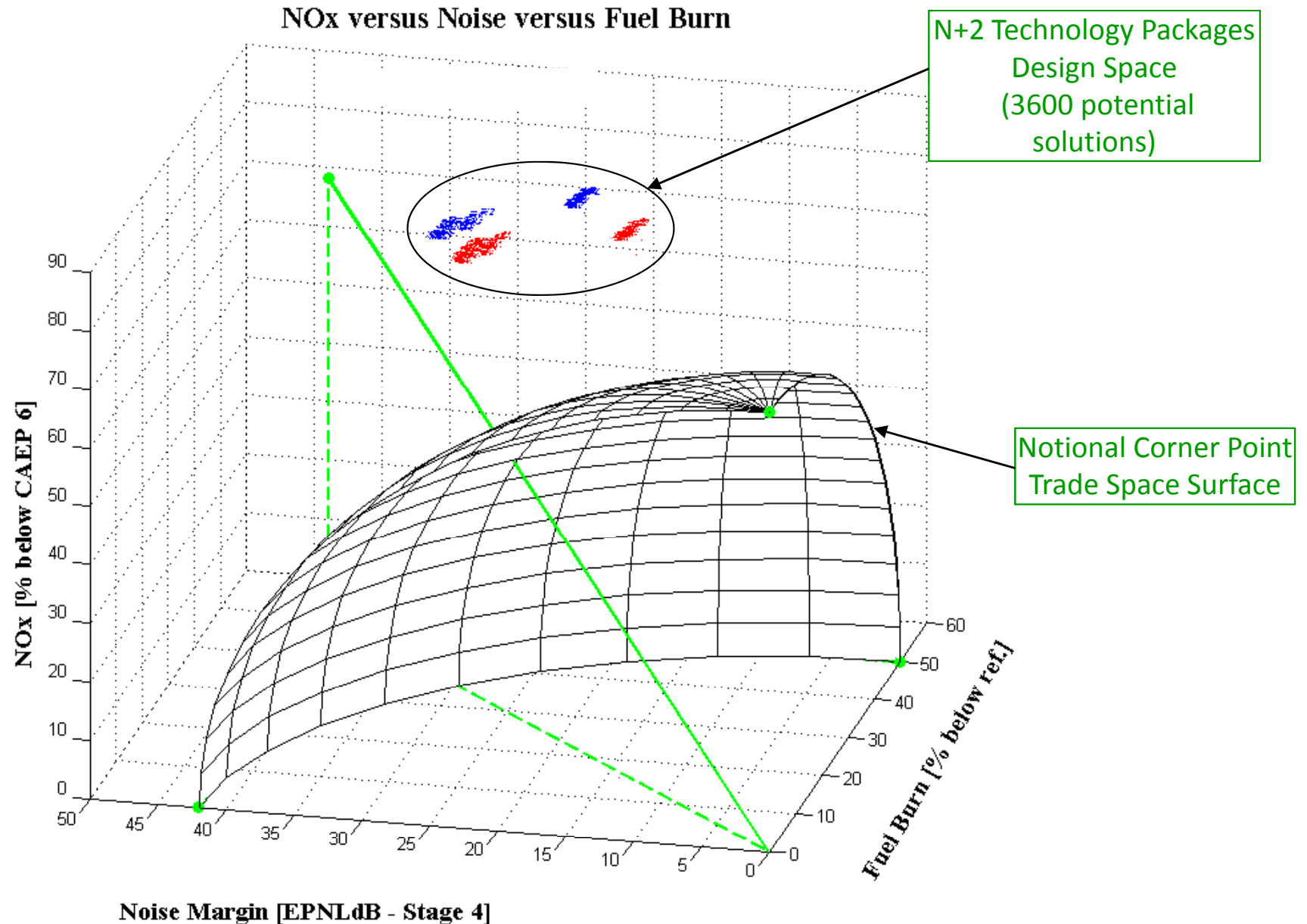
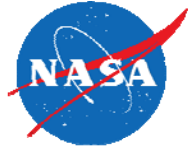
Concept Modeling Summary



	Regional Jet	Single Aisle	Small Twin Aisle	Large Twin Aisle	Very Large
Baseline Vehicle	CRJ900	737-800	767-300ER	777-200ER	747-400
Engine	CF34-8	CFM56-7B27	CF6-80	GE90-94B	PW4056
Passengers	86	174	210	301	416
2025 Tube+Wing					
Fuel Burn	-42.0%	-40.8%	-47.3%	-44.3%	-41.0%
Noise (dB cum below Stage 4)	30.5	24.0	27.1	27.3	22.6
Emissions	-75.0%	-75.0%	-75.0%	-75.0%	-75.0%
2025 HWB					
Fuel Burn	N/A	N/A	TBD	-50.2%	TBD
Noise (dB cum below Stage 4)	N/A	N/A	TBD	43.6	TBD
Emissions	N/A	N/A	TBD	-75.0%	TBD
2025 Concept X					
Fuel Burn					
Noise (dB cum below Stage 4)					
Emissions					

Trade Space Visualization

Advanced LTA Class Tube and Wing

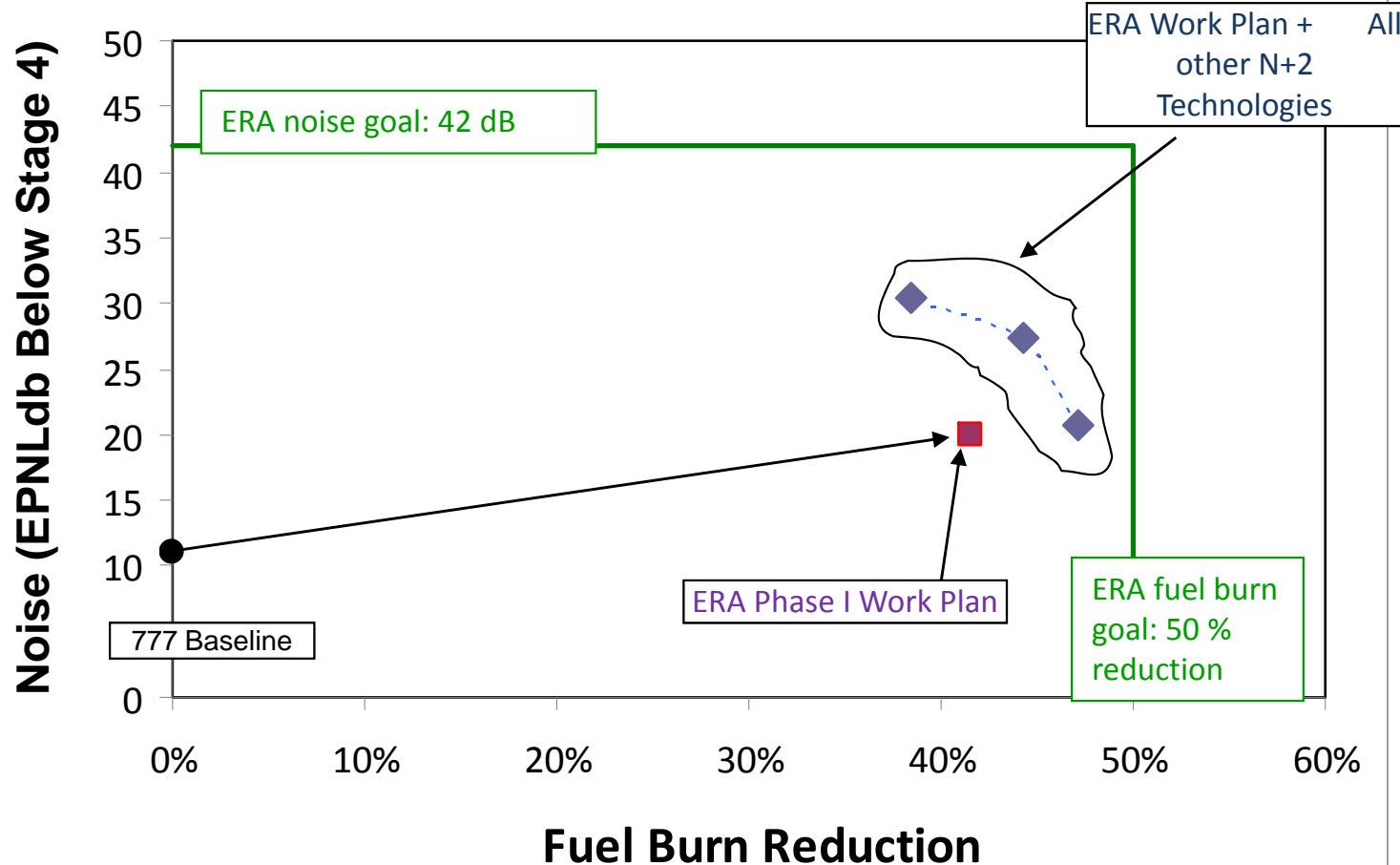


Optimized Points Comparison to Goals

Advanced LTA Class Tube and Wing



LTA Vehicle Assessment

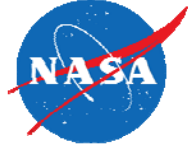


Key Takeaways:

1. ERA Phase I Portfolio makes significant improvements in noise and fuel burn
2. ERA Phase I plan plus all potential N+2 technologies applied to advanced tube and wing will not meet the goal (noise / fuel burn tradeoff)
3. A configuration change is required (configuration itself is a technology) to meet the ERA goal.

Noise / Fuel Burn Tradeoff

Best Technology Package – LTA Class T+W



Airframe Technologies

- Composite Material Technologies
- Stitched Composites/PRSEUS
- Wing Load Alleviation System
- M.E.A. Electro Mechanical Actuators
- Adaptive Wing - T.E. Variable Camber
- Excrescence Reduction
- HLFC - Wing and Tails
- NLF – Nacelles
- Riblets
- Active Flow Control Rudder
- Continuous Moldline Link for Flaps
- Landing Gear Fairings - Main/Nose
- Slat Inner Surface Acoustic Liner
- Slat-Cove Filler

Engine Technologies

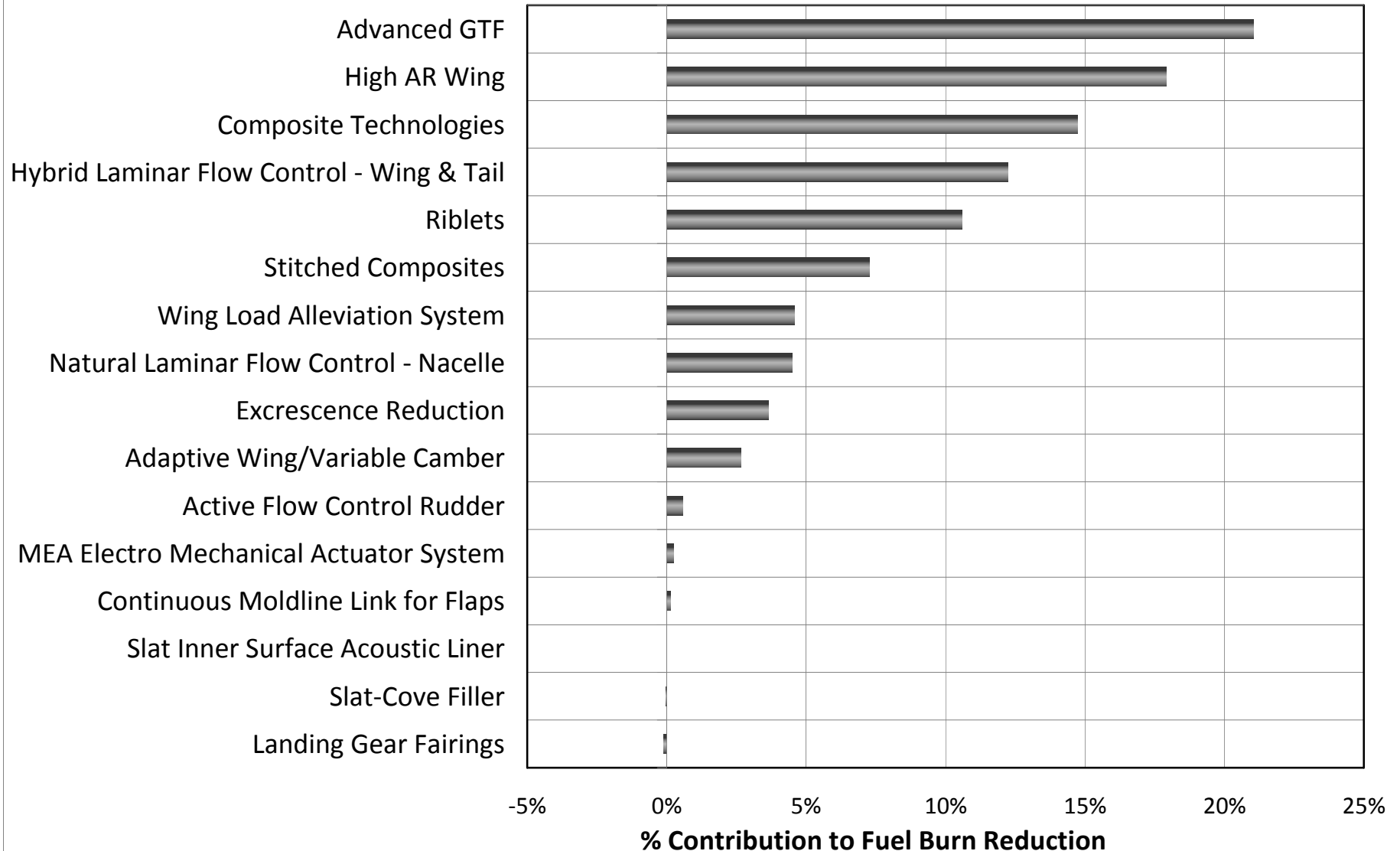
- Active Compressor/Turbine Clearance Control
- Active Compressor/Turbine Flow Control
- Active Film Cooling
- Highly Loaded Compressor/Turbine
- Advanced TBC Coatings
- Advanced Turbine Nickel Based Superalloys
- Ceramic Matrix Composites
- High Temperature Erosion Coating for CMC
- Metal Matrix Composites
- Polymer Matrix Composites
- PMC Fan Blade with Metal Leading Edge
- PMC with High Temperature Erosion Coatings
- Beveled Nozzle
- Combustor Liner
- Herschel-Quincke Tube Liner Integration
- Long-cowl Nacelle Common Nozzle
- Lip Liner
- Over-the-Rotor Metal Foam Liner
- Rotor Sweep
- Soft Vane
- Stator Sweep and Lean
- Variable Geometry Chevrons
- Zero Splice Inlet
- Lightweight CMC Liner
- Advanced Combustor

Green Font = ERA Phase I Technology

LTA Class Advanced T+W Rankings



N+2 Best Compromise Fuel Burn



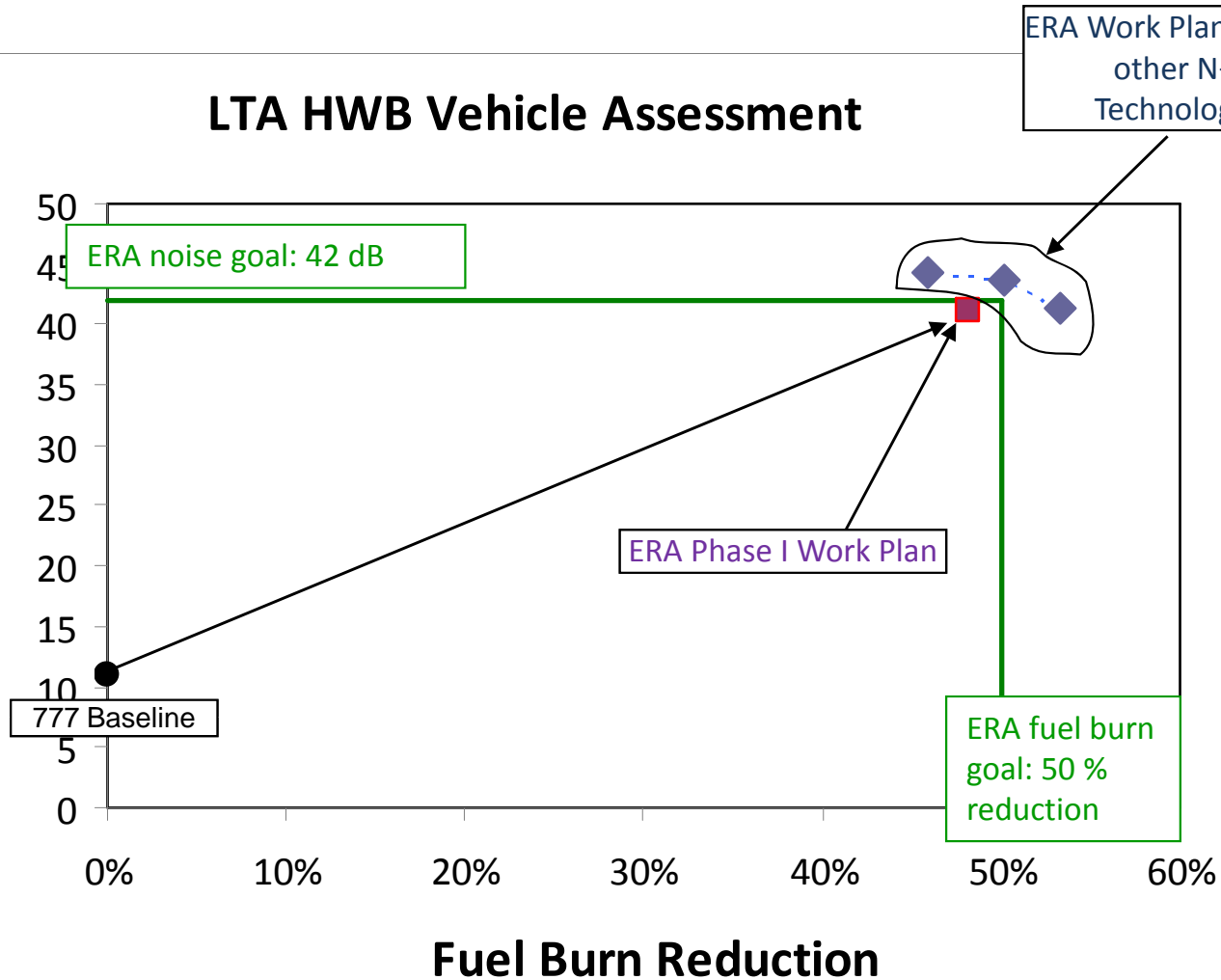
Optimized Points Comparison to Goals

Advanced LTA Class HWB



LTA HWB Vehicle Assessment

Noise (EPNldB Below Stage 4)



Key Takeaways:

1. ERA Phase I Portfolio targeted at HWB
2. ERA Phase I plan plus all potential N+2 technologies plus HWB configuration will meet the ERA goal (noise+ fuel burn+emissions)

Best Technology Package – LTA Class HWB



LTA HWB Airframe Technologies

Composite Material Technologies
Stitched Composites/PRSEUS
Wing Load Alleviation System
M.E.A. Electro Mechanical Actuators
Excrescence Reduction
HLFC - Wing
NLF – Nacelles
Riblets
Landing Gear Fairings - Main/Nose
Slat Inner Surface Acoustic Liner

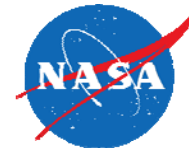
Green Font = ERA Phase I Technology

LTA Engine Technologies

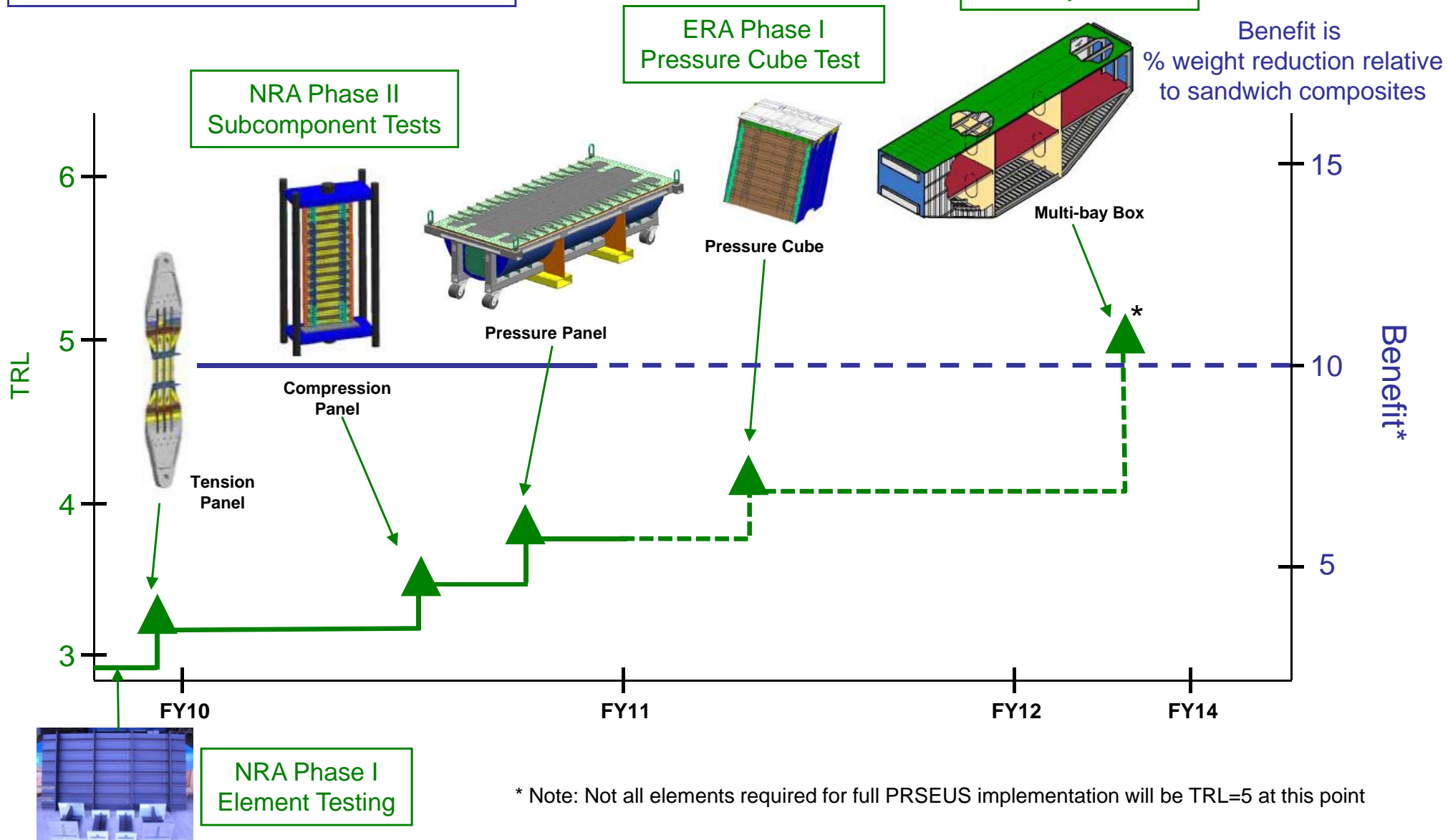
Active Compressor/Turbine Clearance Control
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Highly Loaded Compressor/Turbine
Advanced TBC Coatings
Advanced Turbine Nickel Based Superalloys
Ceramic Matrix Composites
High Temperature Erosion Coating for CMC
Metal Matrix Composites
Polymer Matrix Composites
PMC Fan Blade with Metal Leading Edge
PMC with High Temperature Erosion Coatings
Beveled Nozzle
Combustor Liner
Herschel-Quincke Tube Liner Integration
Long-cowl Nacelle Common Nozzle
Lip Liner
Over-the-Rotor Metal Foam Liner
Rotor Sweep
Soft Vane
Stator Sweep and Lean
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Lightweight CMC Liner
Advanced Combustor

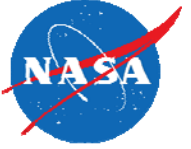
Measuring Progress from the “Bottom Up”

WBS: 2.1 Lightweight Structures
Technology: PRSEUS for the HWB Centerbody
Objective: Reduce primary structural weight



ERA Stitched Composite Airframe Technology Maturation Roadmap





Questions?